

Stochastic atmospheric perturbations in the EC-Earth v3 Earth system model: impact on seasonal predictions

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Outline

- 1 Introduction
 - Stochastically perturbed parameterization tendencies
 - The EC-Earth v3 Earth-system model
- 2 Experiments and evaluation methods
- 3 Main results
 - Ensemble spread and systematic error
 - RMSE
 - Correlation coefficient
 - Probability forecasts : CRPSS
 - Sensitivity to stratospheric tapering layer height
- 4 Main conclusions and future work

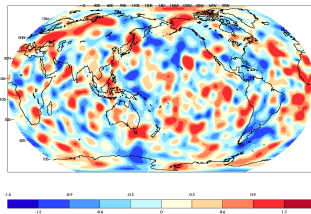
The SPPT method

Description

- Method developed at ECMWF (Buizza et al., 1999 ; Palmer et al., 2009)
- Random multiplicative coefficients applied to physical tendencies of atmospheric variables
- $X_p = (1 + \mu r)X_c$; with $X = u, v, T, q$
- Spectral coefficients of r are defined by an AR(1) process forced with gaussian random numbers ; μ is used to taper perturbations close to the surface and in the stratosphere

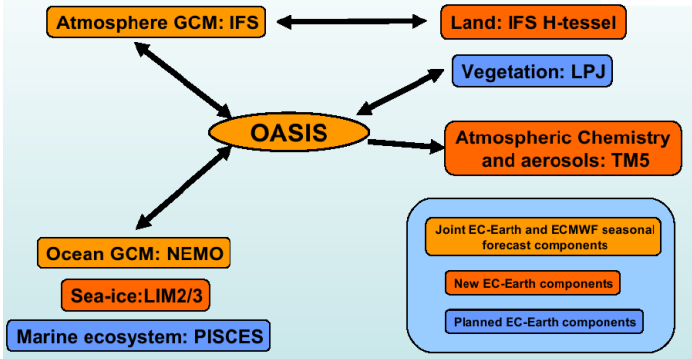
r patterns

- Space and time decorrelation scales
- Several patterns can be linearly combined
- Same r for all variables and model levels



Seasonal forecasts with the EC-Earth v3 ESM

EC-EARTH components

Source : EC-Earth website eearth.knmi.nl

Seasonal forecasts with the EC-Earth v3 ESM

Atmospheric component

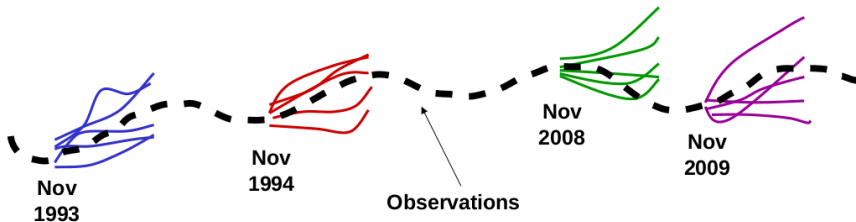
- IFS cycle 36r4, T255 horizontal resolution (0.7°)
- 62 or 91 vertical levels ; 45-minute timestep
- ICs : ERA-Interim reanalysis
- Ensemble generation : singular vector perturbations

Ocean and sea-ice

- NEMO v3.2 with LIM2 sea-ice component, ORCA1 grid (1° nominal resolution)
- 46 vertical levels ; 1-hour timestep
- ICs : GLORYS v2.1 analysis
- Coupling with atmosphere : every 6 hours

Seasonal forecasts : methodology

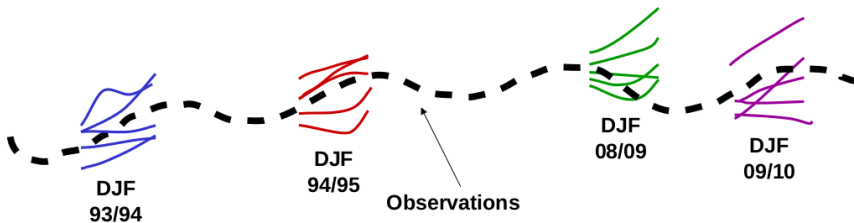
Example for December-January-February (DJF) hindcasts



Ensemble predictions initialized each November

Seasonal forecasts : methodology

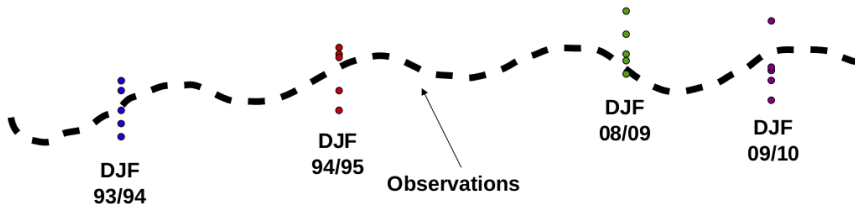
Example for December-January-February (DJF) hindcasts



Months 2-4 of each ensemble member are selected

Seasonal forecasts : methodology

Example for December-January-February (DJF) hindcasts



3-month means for each member : compared to reference data seasonal means

Seasonal hindcast evaluation

Variables and reference data

Sea-surface temperature	}	ERA-Interim reanalysis
2-meter air temperature		
Sea-level pressure		
Total precipitation	}	GPCP v2.2 precipitation data

Ensemble statistics

- ✓ Systematic error
- ✓ Ensemble spread

Forecast skill assessment

- ✓ Root Mean Square Error
- ✓ Anomaly Correlation
- ✓ Continuous Ranked Probability Skill Score

Results shown here are for DJF (November startdates) and 62-level resolution, unless specified otherwise.

Sets of experiments

REF experiments : initial perturbations only

- T255L62 resolution : 5-member ensemble hindcast starting in May and November 1993 to 2009
- T255L91 resolution : 10-member ensemble (same startdates)

SPPT experiments : decorrelation scale sensitivity tests

Name	Nv levels	Scale 1			Scale 2			Scale 3		
		σ	Δx (km)	Δt (days)	σ	Δx (km)	Δt (days)	σ	Δx (km)	Δt (days)
SPPT3	62, 91	0.125	2000	30	0.250	1000	3	0.500	500	0.25
SPPT2L	62, 91	0.288	2000	30	0.173	1000	10	-	-	-
SPPT3L	62	0.125	2000	30	0.150	1000	10	0.250	500	3

Stratospheric tapering zone height sensitivity test

For 91-level resolution only ; tapering zone moved from between 100 and 50 hPa to between 50 and 5 hPa in SPPT3 experiment : **SPPT3st**

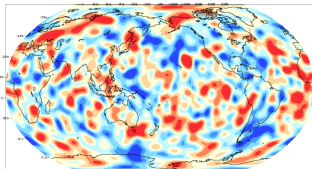
SPPT r pattern decorrelation time and space scales

3-scale SPPT

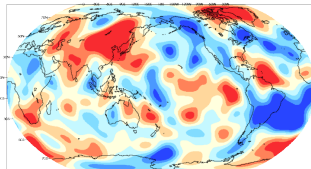
- 6 hours ; 500 km ; $\sigma_1 = 0.5$
- 3 days ; 1000 km ; $\sigma_2 = 0.25$
- 30 days ; 2000 km ; $\sigma_3 = 0.125$

Larger 2-scale SPPT

- 10 days ; 1000 km
- 30 days ; 2000 km
- $\sigma_1 = 0.29$; $\sigma_2 = 0.17$



Timestep 1



Timestep 1



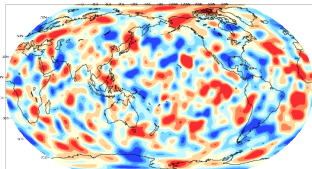
SPPT r pattern decorrelation time and space scales

3-scale SPPT

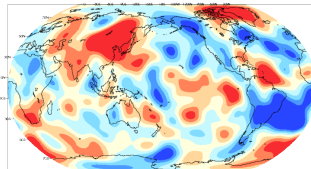
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Timestep 2



Timestep 2



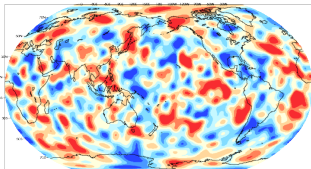
SPPT r pattern decorrelation time and space scales

3-scale SPPT

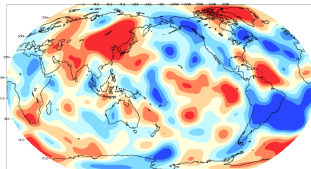
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Larger 2-scale SPPT

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Timestep 3



Timestep 3



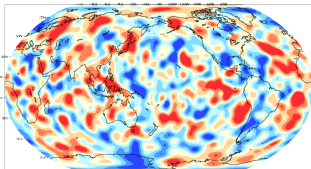
SPPT r pattern decorrelation time and space scales

3-scale SPPT

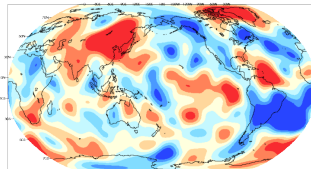
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Larger 2-scale SPPT

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Timestep 4



Timestep 4



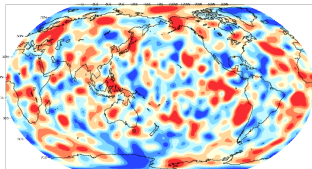
SPPT r pattern decorrelation time and space scales

3-scale SPPT

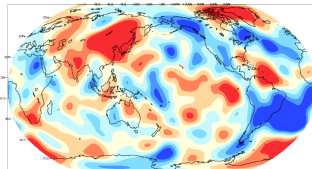
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Timestep 5



Timestep 10



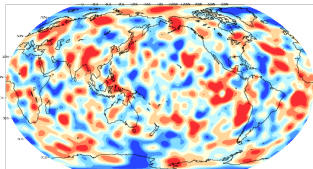
SPPT r pattern decorrelation time and space scales

3-scale SPPT

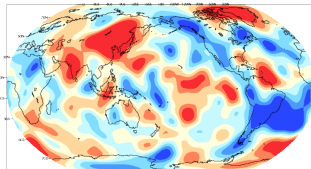
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- 30 days ; 2000 km ; $\sigma_3 = 0.125$

Larger 2-scale SPPT

- 10 days ; 1000 km
- 30 days ; 2000 km
- $\sigma_1 = 0.29$; $\sigma_2 = 0.17$



Timestep 6



Timestep 20



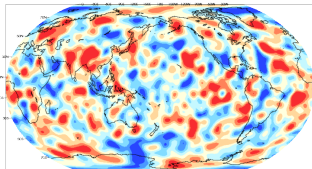
SPPT r pattern decorrelation time and space scales

3-scale SPPT

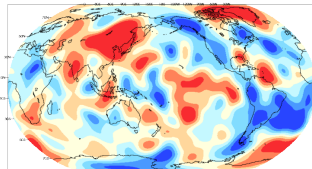
- 6 hours ; 500 km ; $\sigma_1 = 0.5$
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Larger 2-scale SPPT

- 10 days ; 1000 km
- 30 days ; 2000 km
- $\sigma_1 = 0.29$; $\sigma_2 = 0.17$



Timestep 7



Timestep 30



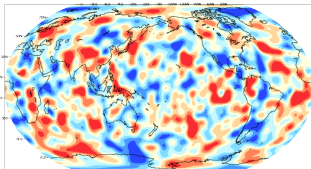
SPPT r pattern decorrelation time and space scales

3-scale SPPT

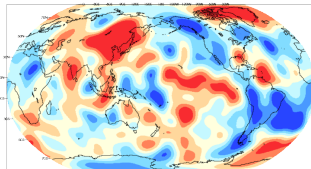
- 6 hours ; 500 km ; $\sigma_1 = 0.5$
- 3 days ; 1000 km ; $\sigma_2 = 0.25$
- 30 days ; 2000 km ; $\sigma_3 = 0.125$

Larger 2-scale SPPT

- 10 days ; 1000 km
- 30 days ; 2000 km
- $\sigma_1 = 0.29$; $\sigma_2 = 0.17$



Timestep 8



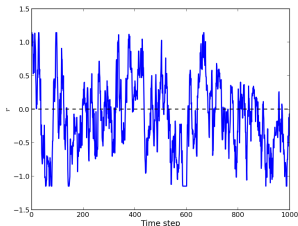
Timestep 40



SPPT r pattern decorrelation time and space scales

3-scale SPPT

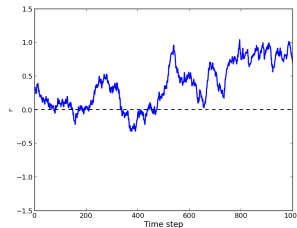
- 6 hours ; 500 km ; $\sigma = 0.5$
- 3 days ; 1000 km ; $\sigma = 0.25$
- 30 days ; 2000 km ; $\sigma = 0.125$



Time series of r at one gridpoint

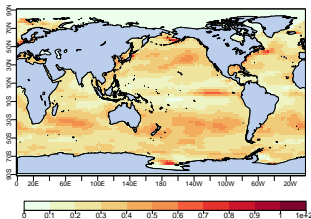
Larger 2-scale SPPT

- 10 days ; 1000 km
- 30 days ; 2000 km
- Different sets of σ

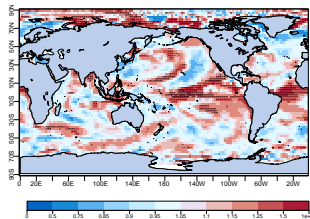


Time series of r at one gridpoint

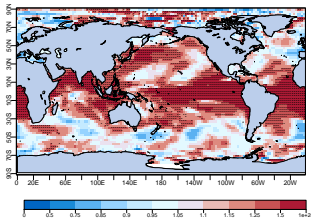
Impact on ensemble spread : SST



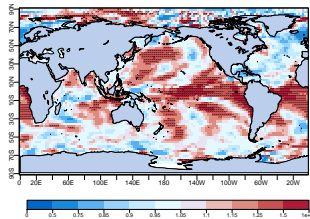
DJF REF spread



DJF SPPT3 relative spread

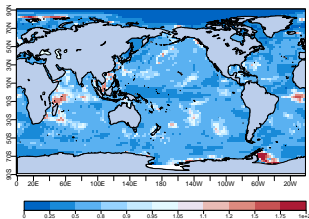


DJF SPPT2L relative spread

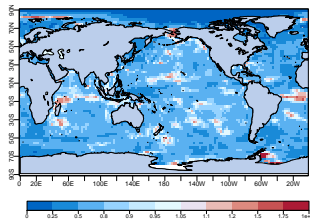


DJF SPPT3L relative spread

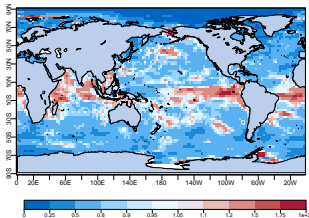
Impact on ensemble spread vs skill : SST



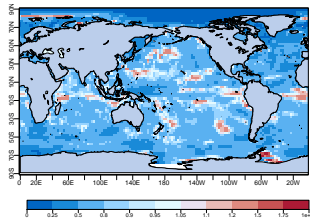
DJF REF spread



DJF SPPT3 spread/skill

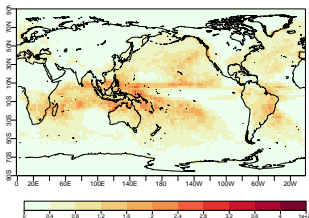


DJF SPPT2L spread/skill

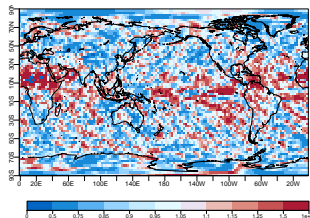


DJF SPPT3L spread/skill

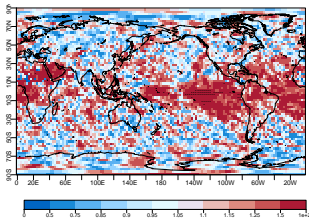
Impact on ensemble spread : Precipitation IQR



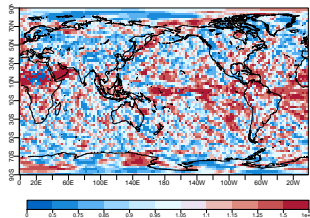
DJF REF interquartile range



DJF SPPT3 relative IQR

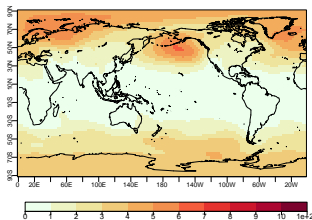


DJF SPPT2L relative IQR

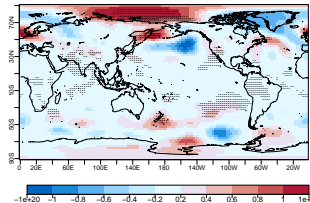


DJF SPPT3L relative IQR

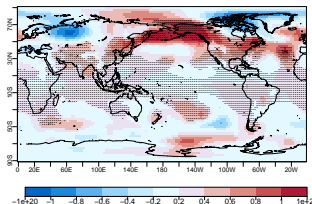
Impact on ensemble spread : Sea-level pressure



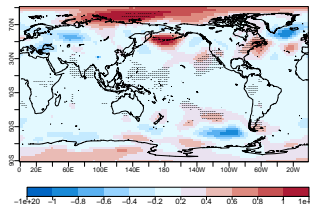
REF spread



SPPT3 difference

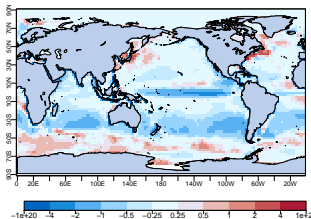


SPPT2L difference

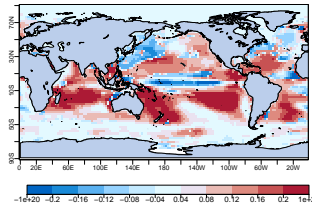


SPPT3L difference

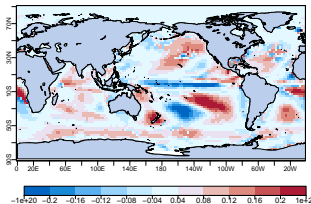
Impact on systematic error : SST



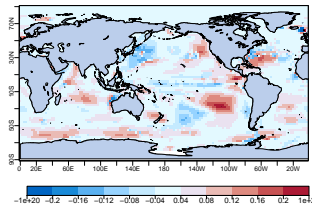
DJF REF systematic error



DJF SPPT3 absolute difference

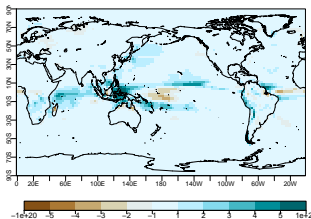


DJF SPPT2L absolute difference

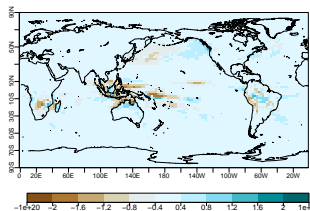


DJF SPPT3L absolute difference

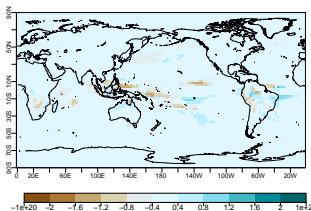
Impact on systematic error : Precipitation



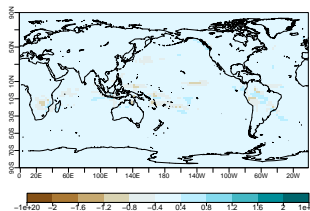
DJF REF systematic error



DJF SPPT3 absolute difference

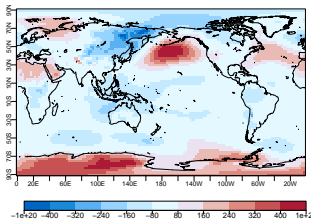


DJF SPPT2L absolute difference

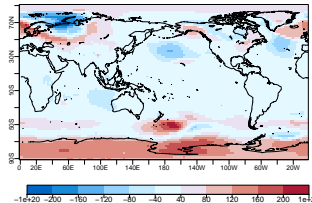


DJF SPPT3L absolute difference

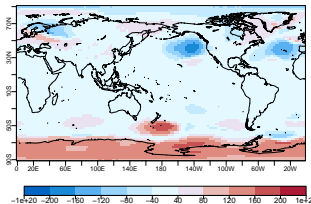
Impact on systematic error : Sea-level pressure



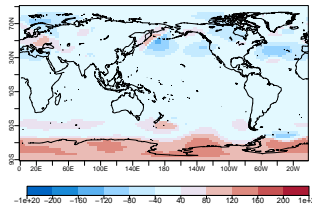
DJF REF systematic error



DJF SPPT3 absolute difference



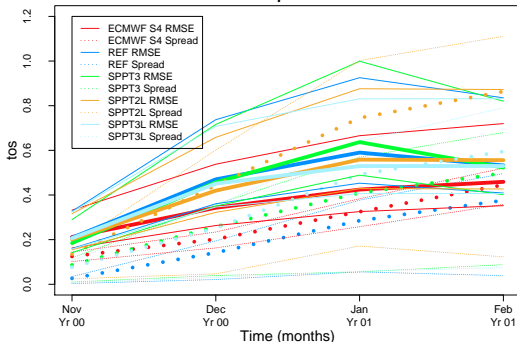
DJF SPPT2L absolute difference



DJF SPPT3L absolute difference

Spread and RMSE over the Niño 3.4 region

RMSE and spread over N34

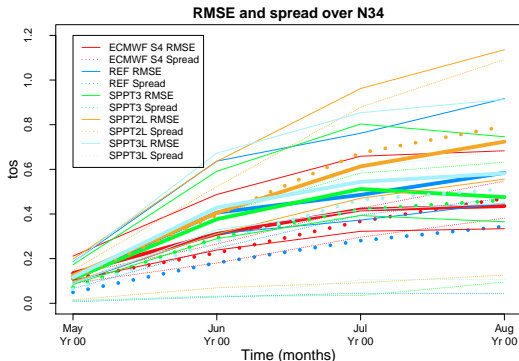


Spread (dots) and RMSE (lines) for Niño 3.4 SST hindcasts using ECMWF system 4 and EC-Earth without (REF) and with SPPT; thin lines show the 95% confidence interval

62-level configuration

- ECMWF system 4 hindcast in red
- EC-Earth 3 without SPPT has low spread and higher RMSE than System 4
- Including SPPT significantly increases spread without increasing RMSE
- except in the SPPT2L case for JJA

Spread and RMSE over the Niño 3.4 region

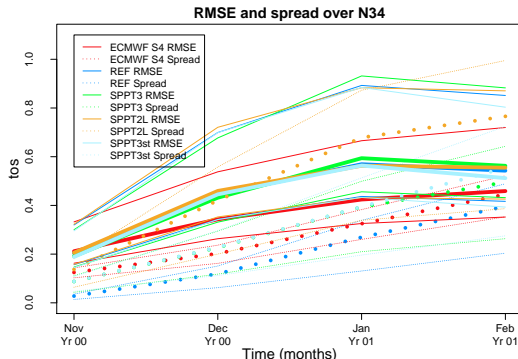


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Spread and RMSE over the Niño 3.4 region

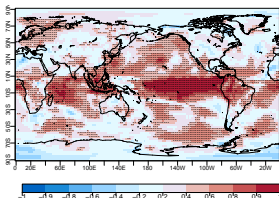


91-level configuration

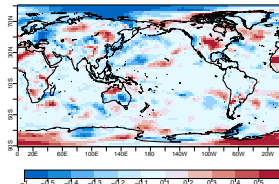
- Similar conclusions than for the 62-level experiments
- SPPT2L is over-dispersive for Niño 3.4 SST
- Perturbing higher in the stratosphere has almost no influence

Spread (dots) and RMSE (lines) for Niño 3.4 SST hindcasts using ECMWF system 4 and EC-Earth without (REF) and with SPPT; thin lines show the 95% confidence interval

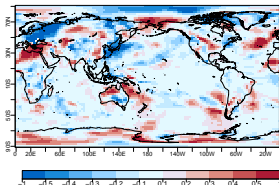
Correlation coefficient : 2-meter temperature



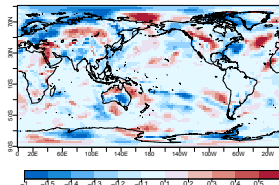
DJF REF correlation



DJF SPPT3 difference



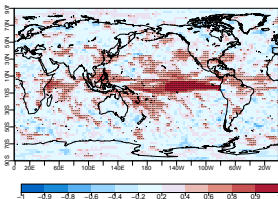
DJF SPPT2L difference



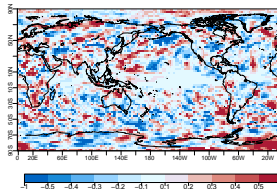
DJF SPPT3L difference

(Linear trends over the 1993-2009 time period are removed)

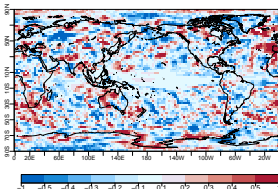
Correlation coefficient : precipitation



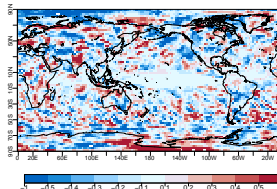
DJF REF correlation



DJF SPPT3 difference



DJF SPPT2L difference



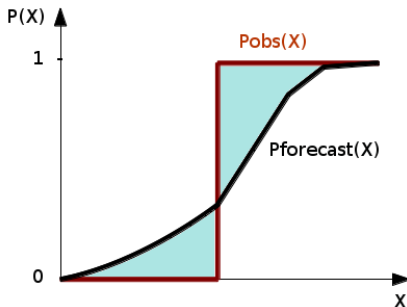
DJF SPPT3L difference

(Linear trends over the 1993-2009 time period are removed)

Continuous Ranked Probability Skill Score

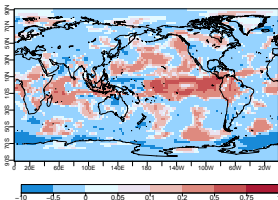
Probability forecasts evaluation

- CRPS : difference between observed and forecast CDFs
- $CRPS = \int_{-\infty}^{+\infty} (P_{forecast}(X) - P_{obs}(X))^2 dX$
- Skill score : $CRPSS = 1 - \frac{CRPS_{model}}{CRPS_{clim}}$
- Perfect score : $CRPSS=1$; $CRPSS>0$ shows model has additional skill with respect to climatology

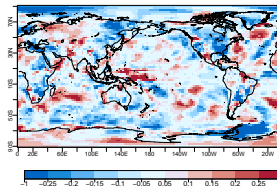


CRPSS for 2-meter temperature DJF hindcasts

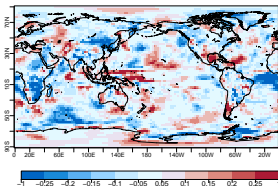
91-level hindcasts (10-member ensembles)



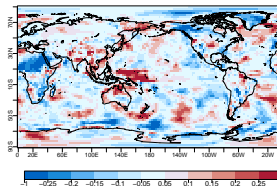
DJF REF CRPSS



DJF SPPT3 difference



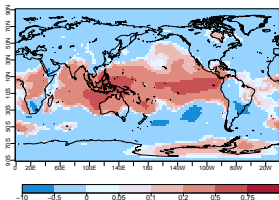
DJF SPPT2L difference



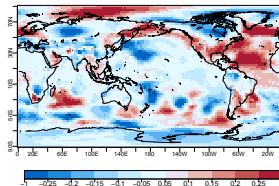
DJF SPPT3st difference

CRPSS for sea-level pressure DJF hindcasts

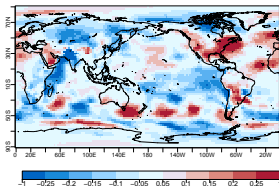
91-level hindcasts (10-member ensembles)



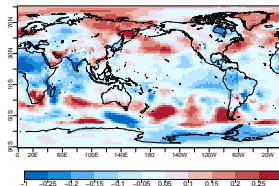
DJF REF CRPSS



DJF SPPT3 difference

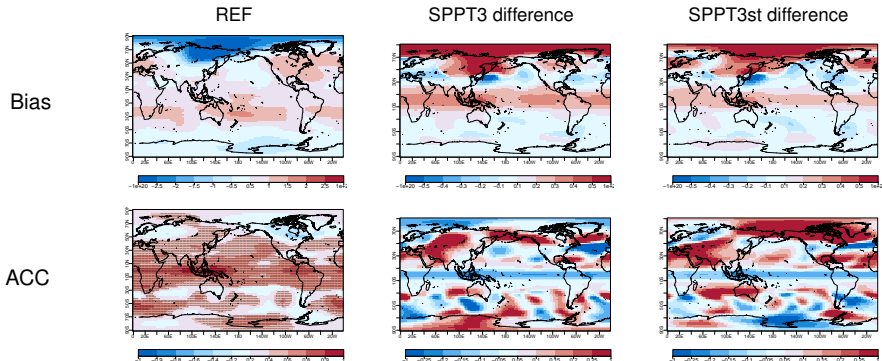


DJF SPPT2L difference

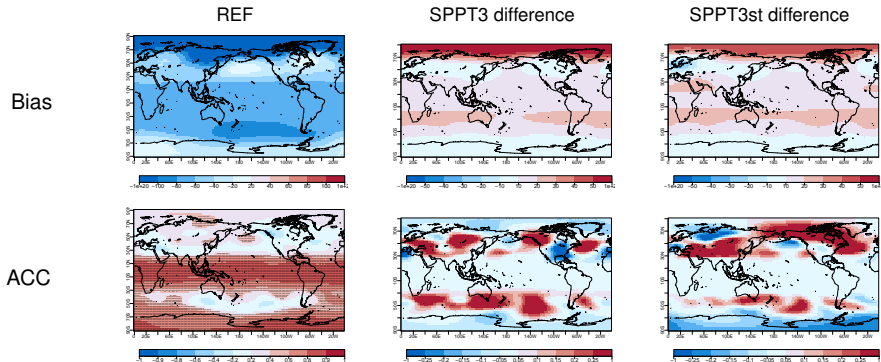


DJF SPPT3st difference

Impact of stratospheric tapering layer height on 50hPa temperature



Impact of stratospheric tapering layer height on Z50



Main conclusions on SPPT

Impact of SPPT on EC-Earth seasonal forecasts

- Larger scale SPPT hindcast experiment has larger spread at a seasonal time scale
- Tropical Pacific region : better spread-to-skill ratio
- Moving the tapering zone higher in the stratosphere improves Z50 and T50 correlation skill at high latitudes

Further assessments

- Evaluation of daily outputs : weather regimes, precipitation distributions
- Impact on the Arctic region
- Impact on the ocean component

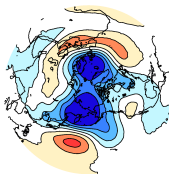
Stochastic dynamics method

Description

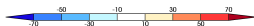
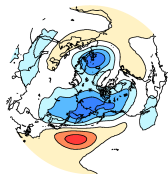
$$\mathbf{X}(t + \Delta t) = \mathbf{X}(t) + \mathbf{M}(\mathbf{X}(t), t) + \delta\mathbf{X}$$

- $\mathbf{X} : T, q, \Psi$
- $\delta\mathbf{X}$: error correction term derived from a previous nudged seasonal run
- Perturbations are simultaneous corrections of global fields for Ψ, Q, T
- "Stochasticity" : random draws of a different $\delta\mathbf{X}$ for each member

Bias INI



Bias SD RAND



Mean Z500 bias (m) in DJF 1979–2010 seasonal hindcasts with the CNRM-CM5 climate model

Work in progress...

This method (Batté and Déqué, 2012) is currently being implemented in the IFS atmospheric model and will be tested with the EC-Earth v3 ESM.

Thanks for your attention !



Climate Forecasting Unit





Climate Forecasting Unit



Pattern generator for r

Spectral transform of r : $r = \sum_{mn} \hat{r}_{mn} Y_{mn}$

Spectral coefficients follow AR(1) process :

$$\hat{r}_{mn}(t + \Delta t) = \phi \hat{r}_{mn}(t) + \sigma_n \nu_{mn}(t) \quad (1)$$

$$\text{Re}(\nu_{mn}) \sim \mathcal{N}(0, 1) ; \text{Im}(\nu_{mn}) \sim \mathcal{N}(0, 1) ;$$

One-timestep correlation : $\phi = \exp(-\Delta t / \tau)$

Variance spectrum of \hat{r}_{mn} depends on the total wavenumber as $\exp(-\kappa T n(n+1))$